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ABSTRACT

We show that string theory predicts the existence of a second unification hierarchy and several new forces. Bars, Kounnas and Deliduman have gauged Sp(2) duality to develop matrix-string theories with two time dimensions, and two physical sectors. They suggest that one time dimension is in the coordinate sector and the other is in the momentum sector. We show that the phenomena of quantum mechanics, offer experimental support for this dual structure. We develop this theory to show that there are two unification hierarchies, one in each sector. The known unification hierarchy is in the momentum sector. The new unification hierarchy is in coordinate space, and it gives rise to three new forces (x-strong, x-weak and x-electromagnetic, and possibly to their duals). These new forces in the coordinate sector do not interact with matter in the normal way and so have not previously been recognized. We identify the order force with the coordinate-space form of the strong interaction.

Introduction

In the previous paper, we have shown that there is evidence for a new force of nature, which has nuclear properties and acts over distances of several tens of fermis. It has the same strength as the Unified Field and so it must be associated with the Unified Field in some way, presumably more directly than normal forces. We call this new force the "order force". We show below that string theory with two time dimensions offers an explanation for this new force.

In this paper we show that string theory with two time dimensions, predicts the existence of two physical sectors and that there is a second unification hierarchy in the coordinate sector. This then produces coordinate-space forms of the strong, electromagnetic and weak interactions, and possibly their duals. There are reasons to believe that these forces act on coordinates, as opposed to momenta, and so have unusual properties, such as the ability to create ordered patterns, which are not studied by physicists. If so, this would help to explain why their existence has not been recognized. We identify the order force with the coordinate form of the strong interaction, and we show that it has the same coupling constant as the Unified Field, because symmetry breaking in coordinate space is weak because the coordinate sector is decompactified.

String Theory

Duality symmetries have been used to unite the five known 10-dimensional (9,1) superstring theories into a single theory in eleven dimensions (10,1).[2] M theory, or 'matrix-string theory', is also the non-perturbative extension of 11-dimensional supergravity.[3] A candidate for matrix-string theory has recently been proposed.[4] The successful unification of these five supersymmetry theories in one higher dimension, has led to the exploration of supersymmetry in 12, 13 and 14 dimensions. This was first done by increasing the number of time dimensions to two.[5] Vafa has shown the power of F-theory in (10,2)-dimensions to unify a large class of string vacua in a non-trivial way.[6] There are other reasons pointing to a (10,2) dimensional target space.[7] More recently it has been suggested that the fundamental supersymmetric theory may exist in 11 space-like and 3 time-like dimensions (11,3).[8] Furthermore, Sezgin has found that the supersymmetric theory in (10,2) dimensions of [4] can be generalized naturally to (11,3) dimensions, whilst extensions beyond (11,3) dimensions run

into problems.[9] So whilst matrix-string theory in (10,1) dimensions looks interesting, the correct theory may be in (10,2) or even (11,3) dimensions.

One of the problems with research into string theory is that it has been found to be difficult to relate it to experiment. It is thus of interest that Bars and Kounnas have suggested a physical interpretation for a theory with two times (10,2). They point out that the Big Bang is in a certain sense the opposite of a black hole, and then consider evidence from both.

Bars has shown that it is possible to make a 12-dimensional interpretation of the entropy of a string-theory black hole, which provides evidence for the existence of a 12th dimension hidden inside the black hole.[10] Bars and Kounnas point out that calculations of the entropy and mass of certain stringy charged black holes in terms of D-branes,[11] are invariant under transformations that mix the hidden and ordinary dimensions.[12]

At the moment before the Big Bang, the fundamental theory, whose form is unknown but which is assumed to obey S-theory algebra,[13] could be a theory of interacting closed and open super p-branes propagating on space-times of (11,2) or (11,3) dimensions. The Big Bang is seen as a type of white hole singularity, *where a phase transition occurred which triggered the expansion of some of the dimensions whilst others remained compact. Bars and Kounnas propose that one of the time-like dimensions is in the expanding part of the universe and the other is in the compactified part inside microscopic matter.* This would be compatible with the hidden dimension inside the black hole.

They propose that when the phase transition of the Big Bang occurred, some of the p-branes are associated with one time-like dimension in the vacuum (ie coordinate space) which is the expanding part of the universe, whilst the others would be associated with the other time-like dimension and remain in the compactified space inside matter. They do not explain why this should happen. However, their Klein-Gordon type equation for the two particles in their model (equation 18) has also been found in the context of T-duality with dual coordinates by Tseytlin.[14] So this could be due to T-duality.

Thus they conclude that the two time-like dimensions could be real and belong to two physical sectors of a single theory, each with its own time. The vacuum would contain normal time, and the compactified dimensions inside microscopic matter would contain the other time. Thus the internal space of matter would be a Minkowski space, which would play a role in determining the flavour quantum numbers in low energy physics.[15]

We thus have a picture of reality where matter is topologically different from the vacuum and contains a second time dimension.

Supersymmetry

Supersymmetry is not a quantum mechanical gauge symmetry, but a geometrical symmetry. When a boson is rotated through 2π radians, it comes back to the same state, but when a fermion is rotated by 2π radians it goes into a measurably different quantum state. It has to be rotated through 4π radians to come back to its original configuration. Supersymmetry is a deeper more powerful geometrical symmetry which accommodates these differences, by means of an additional four dimensions of "superspace" for fermions. It is normally stated that these extra fermionic dimensions are not ordinary space-time dimensions but simply a mathematical space required to express the peculiar geometrical properties of fermions.

Bars and Kounnas suggest that the particles of matter (fermions) are in a different space from the vacuum. Bars and Kounnas have not explored the relationship between their two physical sectors, and the two spaces of supersymmetry viewed as physical spaces. Are these related? One of the interesting points is that bosons require a less complex space to exist in, and therefore bosons can occur where fermions cannot. It could thus be that the coordinate space of the vacuum contains additional forces.

Local Gauge-invariant Duality and Two Time Dimensions

Since these initial results of Bars and Kounnas, there have been important developments in

theories with two time dimensions, and we present some of these results here. The motivation for doing research into theories with two times has increased because there is further evidence that the final theory will have two or more times. Examples are: the duality properties of superstring and supersymmetry p-brane theories [16], extensions of S theory [10],[17] and models of multi-superparticles that are fully covariant in (10,2) and (11,3) dimensions.[18,19,20]

Furthermore, if one unifies dualities, supersymmetry, and Lorentz invariance one gets a structure in 14 dimensions with three timelike dimensions (11,3) [17].[21,22] In order to make sense of extra timelike dimensions, it is only necessary to study systems with two timelike dimensions because the conceptual jump from one to two timelike dimensions can be easily extended to three.

This work on theories with two times has developed in three phases:

A. Firstly, one considers two particles described by their world lines $x_1^\mu(\tau), x_2^\mu(\tau)$. Then by means of a suitable choice of action and requiring that it be gauge invariant under n independent infinitesimal reparametrizations [12,18,19],[23] one obtains the following constraints on the on-shell momenta of the two particles [23]:

$$p_1^2 + m_1^2 = 0, \qquad p_2^2 + m_2^2 = 0, \qquad p_1 \cdot p_2 = 0 \tag{1}$$

Apart from the mutual constraint that the momenta are orthogonal, $\mathbf{p_1 . p_2}=0$, the two particles move freely. Two timelike momenta that are orthogonal, cannot exist in a space with a single timelike dimension. It is this requirement that the momenta are orthogonal which forces the existence of a second timelike dimension.

In fact, this set of constraints has a solution provided that there are two or more timelike dimensions with SO(d,2) spacetime symmetry if the particles are massless, or SO(d-1,2) if they are massive. However, because of these constraints, one of the timelike dimensions is removed. The two particles have the momenta p_1^μ, p_2^μ, and position coordinates x_1^μ, x_2^μ, respectively. The index μ has the values 0´,0,1,2...(d-2) in (d,2) dimensions. Each position coordinate has two timelike dimensions with the indices $\mu=0',0$. The constraint that the momenta are orthogonal, $p_1.p_2=0$, removes the timelike dimensions $p_1.x_2$ and $p_2.x_1$, but does not break the SO(d,2) symmetry of the overall system. As a result, the motion of the first particle in the background of the second is equivalent to motion in a subspace with a single timelike dimension with SO(d-1,1) spacetime symmetry [12]. The same result applies to the second particle in the background of the first, except that its single timelike dimension is the orthogonal one. So this mutual constraint that the momenta are orthogonal was the first step in developing a theory with two timelike dimensions and the interpretation given above.

There is no confusion with having to introduce two Hamiltonians because there is a single worldline parameter τ that appears in $x_1^\mu(\tau), x_2^\mu(\tau)$.

Bars and Deliduman then generalized this to two systems (numbers 1 and 2), each containing any number of p-branes or interacting particles [18]. They show that the *total* momenta of each system, $P_{1\mu}, P_{2\mu}$, replace the momenta p_1^μ, p_2^μ of individual free particles in the orthogonal momentum constraint above that removes the extra timelike dimension. They thus find that their theory describes any number of particles or p-branes in a spacetime with two timelike dimensions. Thus this theory with two times gets around the usual problems of such theories, and there are no ghosts.

B. Secondly, Bars, Kounnas and Deliduman generalized this model to the supersymmetric case of a superstring and a massive or massless superparticle, whose total momenta are $P_{2\mu}$, and $P_{1\nu}$, respectively [18,23]. They investigate superparticle and superstring actions that are invariant under the new superstring algebra:

$$\{Q_\alpha, Q_\beta\} = \gamma^{\mu\nu}_{\alpha\beta} P_{1\mu} P_{2\nu}, \qquad P_1 . P_2 = 0 \tag{2}$$

where Q_α is the Majorana-Weyl spinor of SO(10,2) or SO(9,2) with 32 real components. This system is critical and covariant in (9,2) dimensions if the superparticle is massive, and in (10,2) dimensions if the superparticle is massless. Both the superparticle and the superstring have coordinates with two timelike dimensions. However, each behaves as if it has a single timelike dimension, because of the gauge symmetries and associated constraints. This is generalized to two systems containing

interacting constituents.

This superalgebra is the simplest in 12 dimensions. They show that there are classical superstring models of type IIA, type IIB or heterotic supersymmetry, in (d-2,2) dimensions, which have this new supersymmetry.

C. Thirdly, Bars and his colleagues introduced a new gauge symmetry Sp(2) [24,25], *that is really a form of gauged duality, which provides a more elegant way of introducing a second time dimension.* We have seen above that two or more timelike dimensions are only possible if there is the appropriate gauge symmetry and constraints to reduce the theory to one with effectively one timelike dimension and no ghosts. They introduced the gauged form of the Sp(2) symmetry as an evolution of the various forms of infinitesimal reparametrization gauge symmetry used above. The difference is that they apply the gauge invariance to a phase space doublet (X^M,P^M) for a single particle, rather than to the positions of several particles (X_1^M, X_2^M...).

There is a well-established symmetry in quantum mechanics between the interchange of coordinates and momenta, which is known as the symplectic symmetry Sp(2), that transforms (x,p) as a doublet. There is an analogous symmetry in electromagnetism. In the absence of sources, Maxwell's equations are symmetric under the interchange of electricity and magnetism, where the electric and magnetic fields are generalized coordinates and momenta. This symmetry, in the presence of particles with quantized electric and magnetic charges, is a discrete version of Sp(2) known as "electric-magnetic duality". It is well-known that the idea of electric-magnetic duality has been generalized in superstring theory, which is now thought to be part of a larger, duality-invariant M, S or F theory. But the origin of this duality is not known. It seems likely that actual "duality" is a gauge symmetry which is a larger symmetry than Sp(2), but contains it.

In the absence of a definition for "duality", Bars, Deliduman and Andreev decided to gauge the continuous Sp(2) duality symmetry, which treats position and momentum (x,p) as a doublet in phase space. The worldline action has the SO(d,2) symmetry acting linearly on target spacetime $X^M(\tau)$ with two times. In order to remove the distinction between position and momentum, they rename them $X_1^M = X^M$ and $X_2^M = P^M$ and define the doublet $X_i^M = (X_1^M, X_2^M)$. The local Sp(2) symmetry acts as follows:

$$\delta_\omega X_i^M(\tau) = \varepsilon_{ik}\omega^{kl}(\tau)X_l^M(\tau) \tag{3}$$

Where $\omega^{ij}(\tau) = \omega^{ji}(\tau)$ is a symmetric matrix containing three local parameters, and ε_{ij} is the Levi-Civita symbol which is invariant under Sp(2,R) and which raises or lowers indices. The Sp(2,R) gauge field $A^{ij}(\tau)$ is symmetric in (ij) and transforms in the standard way $\delta_\omega A^{ij} = \partial_\tau\omega^{ij} + \omega^{ik}\varepsilon_{kl}A^{lj} + \omega^{jk}\varepsilon_{kl}A^{il}$. $D_\tau X_i^M = \partial_\tau X_i^M - \varepsilon_{ik}A^{kl}X_l^M$ is the covariant derivative. The following action is invariant under this gauge symmetry:

$$S_0 = \frac{1}{2}\int_0^T d\tau (D_\tau X_i^M)\,\varepsilon^{ij}X_j^N\eta_{MN} = \int_0^T d\tau\left(\partial_\tau X_1^M X_2^N - \frac{1}{2}A^{ij}X_i^M X_j^N\right)\eta_{MN} \tag{4}$$

It has been shown in [24] that this system only exists non-trivially if η_{MN} includes two timelike dimensions (d,2). *That is to say, the gauge symmetry Sp(2) only exists with a target spacetime that has d spacelike dimensions and two timelike dimensions.* The global SO(d,2) symmetry is therefore present. The canonical conjugates are $X_1^M = X^M$ and $\partial S/\partial X_1^M = X_2^M = P^M$, which is consistent with (X_1^M, X_2^M) being the doublet (X^M, P^M). This action can be generalized in several ways which are consistent with the Sp(2) gauge invariance.

The equations of motion for X_i^M , A^{ij} that follow from the Lagrangian (2) are

$$\begin{pmatrix}\partial_\tau X^M\\ \partial_\tau P^M\end{pmatrix} = \begin{pmatrix}A^{11} & A^{12}\\ -A^{21} & -A^{22}\end{pmatrix}\begin{pmatrix}X^M\\ P^M\end{pmatrix} \tag{5}$$

$$X.X = X.P = P.P = 0 \quad (6)$$

Thus gauging the Sp(2) duality symmetry gives rise to a gauge field with four components A^{ij}, and to the condition that the momenta are orthogonal, so that a particle effectively sees only one "time".

Bars, and his colleagues then apply this theory to a free massless relativistic particle, to the hydrogen atom and to an harmonic oscillator. They find that the familiar massless particle is in d-dimensional Minkowski spacetime, the hydrogen atom is in d-1 space dimensions, and the harmonic oscillator in d-2 space dimensions with its mass identified with a momentum in an extra dimension. Each of these systems may be viewed as residing in a larger spacetime of (d+2) dimensions. The gauge symmetry makes the theory equivalent to one with a single "time". However, the choice of "time" is not unique. Different choices of "time" result in different Hamiltonians which describe seemingly different systems, such as the hydrogen atom or the harmonic oscillator. These different systems are in fact dual to each other.

They found that the Sp(2) duality gauge invariant sector is characterized by a unique unitary representation of the conformal group SO(d,2) with fixed Casimir eigenvalues. Thus, the same quantum Hilbert space is characterized by a unique unitary representation of the group SO(d,2). Then they found that this can describe different physical systems with different Hamiltonians, as a result of different choices of "time". The physical system looks different because the choice of "time" is not unique so that the Hamiltonian looks different, although they come from the same parent system. As a result these different physical systems are related to each other *by a duality that is a gauge symmetry,* and the hydrogen atom and harmonic oscillator are dual to each other and to the free particle at the classical and quantum levels. These are some of the systems which can be described by this model.

These different, but dual, systems are all described by the same unitary representation of SO(d,2), which is realized in terms of different sets of unconstrained canonical variables. For each system a subset of the SO(d,2) generators is diagonalized and a particular combination of the generators gives rise to the Hamiltonian. Each Hamiltonian corresponds to a fixed gauge of the duality symmetry in which "time" is identified by a particular combination of the spacelike coordinates, which include two times $X^{0'}$, X^0. The topology of the (d,2) dimensional spacetime is not the same for each fixed gauge, but each of these topologies is an allowed solution of the equations of motion and the constraint equations that follow from the single action S_0.

This model shows that different physical systems can be embedded in a spacetime with two timelike dimensions without any ghosts. This shows that it is possible to have more than one timelike dimension and describe realistic physics. Thus, not only is two-time physics possible, but it is a basis for unifying many features of one-time physics *in a geometrical manner. Therefore the gauging of Sp(2) duality symmetry takes us one step further towards a single geometrical theory of everything.* Bars and Deliduman point out that this raises questions about the nature of space and time.

Quantum Mechanics and Wave-Particle Duality

In order to investigate further the structure of the two physical sectors introduced by the above theory, and the nature of space and time, we consider the phenomena of quantum mechanics. Wave-particle duality is well-established in quantum mechanics, both theoretically and experimentally.[2] Wave-particle duality is a contradictory phenomenon because it seems to imply that a particle is both a point-like particle and an extended wave.[3] It is now pertinent to ask, in view of the above theory, whether these phenomena of quantum mechanics are due to the unusual structure of space-time.

In more detail, the following quantum mechanical phenomena are well-known:

1. In quantum mechanics, a particle does not have a trajectory.

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[2] Note that the usage of the word "duality" here is different from its normal usage in string theory.

[3] Of course, in string theory a particle is now a vibrating string, but as these strings are so small (10^{-33} cms) they are for practical purposes still point-like for atomic phenomena (10^{-8} cms).

2. A particle propagates as a wave. When the particle is observed, the wave function collapses and the particle is observed to be at a point in space-time or in a particular state.
3. A particle can tunnel quantum mechanically through a potential barrier.
4. The uncertainty principle is given by the following relationships:

$$\Delta p \cdot \Delta x \geq \hbar; \qquad \Delta E \cdot \Delta t \geq \hbar$$

As a result, the spacial coordinate x and its canonically conjugate momentum p cannot both be measured precisely. Einstein, Podolsky and Rosen have shown that: "either (1) the quantum mechanical description of reality given by the wave function is not complete or (2) when the operators corresponding to two physical quantities do not commute the two quantities cannot have simultaneous reality".[26] Aspect and his colleagues have since tested this experimentally and found that quantum mechanics is complete,[27] so that the above pairs of canonically conjugate variables cannot be simultaneously real. One can observe one sector (eg coordinates) or the other sector (momenta) but not both. *We suggest that this is evidence for two physical sectors, as proposed by Bars and Kounnas.*

In view of this experimental support for the theory that x and p are in separate physical spaces, we use the above theory to present the following scenario (we shall elaborate on this below): There are two physical sectors, coordinate space and momentum space, which are related by duality. These two sectors were created at the time of the Big Bang. After the Big Bang, coordinate space has unfolded to form the vacuum, whilst the higher dimensions of momentum space have remained compacted, which forms the particles of matter. Thus in the view of Bars and Kounnas, coordinate space forms the basis for the vacuum. In practice, the vacuum may be more than coordinate space, because it may contain other influences. For example, the lower dimensions from the momentum sector could overlap the lower dimensions from coordinate space to form the 4-D space-time we observe. This may explain the way in which momentum appears to be expressed as motion in the vacuum. In the model of Bars and Kounnas, each space has d coordinates. Massive particles in momentum space have d-1 dimensions, which allows for one dimension to overlap the vacuum. A later version of the theory may require more. Massless particles, such as the photon, exist in d dimensions.

We now show how the above four quantum mechanical phenomena give experimental support for this dual structure of space and time:[4]

1. The fact that a particle of matter does not have a trajectory, can be understood *if the particle is not actually in the coordinate space,* because then it could not have a trajectory there.
2. Wave-particle duality could be explained if the particle is in one space (momentum space) and the wave function describes its mapping onto the other (coordinate) space.[28] One can then understand the process of observation as one which collapses the wave function and "puts" the particle at the point or state it is observed to be at in coordinate space-time. This suggests that observation takes place in coordinate space, and thus in the vacuum.
3. Quantum mechanical tunnelling may be possible because of these two physical sectors. For example, if the particle is in one sector and the potential barrier is in the other, then one can understand why the particle can "tunnel" through the barrier, because strictly speaking it does not tunnel, but is mapped onto coordinate space on both sides of the barrier. This could help to explain why tunnelling is superluminal - the particle is already on both sides of the barrier.
4. The momentum of a particle is defined in one space (the momentum sector), and the position of it in the other (coordinate) sector. If one can only make observations in one sector at a time, then one could only determine one canonically conjugate variable at a time. In practice, Heisenberg's uncertainty principle provides a relationship between any conjugate pair. This implies a relationship between these two physical sectors.

The fact that one cannot completely define the particle in the vacuum, suggests that the

[4] We use the word "space" here to include the higher dimensions.

particle is (partially) in a separate space. Thus the facts of quantum mechanics provide support for the suggestion by Bars and Kounnas that there are two physical sectors, and the theory of Bars, Deliduman and Andreev that these two sectors can be identified with momentum space-time and coordinate space-time. We now look for further evidence to support this theory of Bars and his colleagues.

Theory of Two Unification Hierarchies and New Forces

At the time of the Big Bang there was a single field, the Unified Field. Almost instantly as the Universe expanded, gravitation separated from the unified field at the Planck mass in standard theory. Therefore gravity separated from the Unified Field at a higher level than this gauged Sp(2) duality theory, and we ignore it for the rest of this discussion. In the standard theory as the Universe expanded, the strong, weak and electromagnetic interactions then separated from the unified field at about 10^{16} GeV.

We now apply the above theory of Bars, Kounnas, Deliduman and Andreev. The gauged Sp(2) duality symmetry results in a theory with two time dimensions, two physical sectors X and P, and the four gauge fields A^{ij} of equation 5, which derive from the unified field. This theory is based upon the gauge principle which creates position, motion and force out of nothing, as outlined above. Position, motion and force are the basic ingredients of physical reality, and so this duality principle is very fundamental. In addition to these two time dimensions, we assume that this theory has ten space dimensions as in M-theory. However unlike M-theory, this theory has two physical sectors for coordinates and momenta respectively, *which unfold differently after the Big Bang*.

According to Bars and Kounnas, as the Universe expands after the Big Bang, the coordinate sector unfolds to form the vacuum, whilst the momentum sector remains compacted, which forms particles of matter. *Thus matter in this theory originates in the momentum sector.* This difference between the two physical sectors applies particularly to the higher dimensions of each sector. The higher dimensions of the momentum sector remain compacted and so form particles, whilst the higher dimensions of the coordinate sector unfold more or less completely. This difference between the two physical sectors leads to quite different high energy and low energy (long distance) behaviour in the two sectors. Specifically in the momentum sector, the interaction between the unified field and low energy phenomena is blocked by the symmetry breaking of the compacted higher dimensions of that sector, which form granular, particulate matter. However, it is not so blocked in the coordinate sector, where these dimensions are unfolded and there is little or no symmetry breaking. We now show that this difference between the two sectors leads to two unification hierarchies (not one as in the standard theory), and to a second set of (three) forces.

Let us first consider the normal picture of string theory. First there is the unified field at 10^{16} GeV. As one moves down through the higher dimensions to the lower energies and larger distances of target space, there is symmetry breaking and the unified field breaks into its components of the strong, electromagnetic and weak interactions, with different coupling constants for each interaction, so that at low energies $\alpha_{GUT} \neq \alpha_s \neq \alpha \neq \alpha_w$. Normal physics is the study of the interaction of these forces with mass to change momenta.

In the theory of Bars et al, the picture is different. At the level of the unified field, gauging Sp(2) duality creates two physical sectors and converts the unified field into four gauge fields A^{ij}. There are two fields A^{12} and A^{21}, which cause transitions between the momentum sector and the coordinate sector, and vice versa. These do not form normal unification hierarchies, but transitions between them, and so we do not consider them further here. One of these four fields A^{22} acts in momentum space to change momenta, and the other A^{11} acts on coordinates. We assume that the forces derived from A^{22} are located in the momentum sector, because they change momenta, and that the forces derived from A^{11} are located in the coordinate sector.

In normal physics, as we have noted above, force acts to change momenta. Therefore in this theory, the forces of normal physics are derived from the field A^{22}, which leads to the standard unification hierarchy in which symmetry breaking separates out the different forces with different coupling constants as observed. We assume that the strength of A^{22} is the same as that of the unified field, so that $\alpha_{GUT} = \alpha_{22}$.

It is well known that the strong interaction is confined within hadronic matter. Furthermore, the weak interaction is short range and therefore effectively confined to matter. We have shown above that matter is located in the momentum sector of Bars' theory. Therefore the strong and weak interactions are located in the momentum sector. *This is evidence that the (known) unification hierarchy, which comes from A^{22} down through the higher compactified dimensions of matter, is in the momentum sector.* This makes sense because these forces change momenta.

It is interesting to note that gauging Sp(2) duality creates an additional symmetry between X^M and P^M, which has not previously been noticed by physicists. In addition to the force (A^{22}) which acts upon P^M, it creates a field (A^{11}) which acts upon X^M. Thus this theory predicts a second set of forces which act on coordinates. Since the known unification hierarchy is located in the momentum sector, it is therefore logical to assume that these new forces are located in the coordinate sector. In other words, in addition to the known forces of physics, *this theory predicts the existence of a whole new class of forces which we discuss below. Furthermore, it provides a new sector for them to act in, the coordinate sector.*

We have thus shown that this theory predicts the existence of a second unification hierarchy. The reader may be surprised that there is a second unification hierarchy, which physics knows nothing about. But this second hierarchy has unusual properties which make it difficult to detect, as we shall now see.

The Coupling Constants of these New Forces

At the high energy level (10^{16} GeV) we assume that $\alpha_{GUT} = \alpha_{11}$. This field then enters into coordinate space which is decompactified and therefore has little or no symmetry breaking. *Therefore the long-range (low energy) forces it produces will have a strength similar or identical to that of the unified field.*

Let us assume that this second unification hierarchy is similar to the currently known unification hierarchy, *with the main difference being that the symmetry breaking in the coordinate sector is much less, and its forces act on coordinates.* As we have noted above, Bars and Kounnas have proposed that the higher dimensions of the coordinate sector are unfolded and therefore the symmetry breaking in that sector will be much weaker (or non-existent), than that in the momentum sector (where they are compactified to form particles of matter).

From above, we see that the unified field creates the two fields A^{22} and A^{11}, which penetrate down into the momentum and coordinate sectors respectively. We assume that A^{22} and A^{11} are essentially the same field, since they come from the unified field, *but that their properties are modified by the different spaces they are in.* They can both produce 'strong', 'weak' and 'electromagnetic' interactions, it is just that the properties of these forces, such as the coupling constants, are modified by the space they are in:

1. As noted above, x-space forces are similar to their counterparts in the known unification hierarchy, except that they have their origins in the coordinate sector and act on coordinates, instead of momenta. Thus the x-space strong interaction would be non-Abelian with three x-colour charges and eight x-gluons. Likewise, the x-electromagnetic and x-weak interactions, would have properties similar to those of the equivalent known forces.
2. The coordinate sector has little or no symmetry breaking and so A^{11} gives rise to three x-space forces with essentially the same coupling constants. We may call these forces the x-strong, x-weak and x-electromagnetic interactions. We then have $\alpha_{GUT} = \alpha_{11} = \alpha_{x\text{-}s} = \alpha_{x\text{-}em} = \alpha_{x\text{-}w}$, to first order.
3. In this theory, whilst the vacuum has many properties similar to that of the coordinate sector, we have seen above that quantum mechanics shows that it actually consists of an overlap of these two sectors. Coordinate space has unfolded to form the vacuum, whilst momentum space has tended to remain compacted, which forms the particles of matter. Each sector has d = 10 spacelike coordinates. Massive particles in momentum space have d-1 dimensions. Massless particles exist in d dimensions. Thus there may be (extended) massless "particles" in the vacuum.

It is clear that the coordinate sector is quite different from the momentum sector of normal

physics. Instead of the strong symmetry breaking, matter, and forces which change momenta, there is little or no symmetry breaking, no matter (or at least no massive matter as we know it) and the x-space forces act to change coordinates. It is possible that in the absence of symmetry breaking, the unified field can act through these x-space forces to create stable ordered patterns. This is a very different reality from the one we have normally studied in physics. Without particles of matter to observe, it is very ghostly. We do not know what is happening, because we cannot detect it in the normal way. This explains why the existence of these forces has not been recognized before.

It is in fact very instructive to contemplate the idea that there is a whole new physical sector, 50% of reality, which physics knows nothing about. This might start to explain the large amounts of dark matter and dark energy in the Universe, which cannot be observed directly, but which cosmological measurements suggest exist.

The Properties of the X-Space Strong Interaction

Let us first consider the known unification hierarchy in the momentum sector. We have shown above that ordinary matter has its origin in this sector. It is also well-known that the strong interaction is confined within matter, and therefore confined to the momentum sector.[29] Now let us consider the coordinate sector. There is no matter there, at least not of the kind we would recognize as matter. Therefore, the x-strong interaction cannot be confined in the normal way, although its range may eventually be limited in some other way. The known strong interaction is thought to be so strong that it confines itself. The coupling constant of the x-strong interaction $\alpha_{x\text{-}s} = 0.04$, which is only about 4% of that of the strong interaction at low energies ($\alpha_s = 1$), and therefore it is going to be much less self-limiting. *The absence of normal matter in the coordinate sector and the reduced strength of this force, mean that x-gluons will not be confined as are normal gluons.*[30]

We have seen that gauging Sp(2) duality creates position, momentum and force, the principle concepts of physics. It also creates the two sectors for X^M and P^M. If one thinks about this carefully, one sees that it also creates an additional symmetry between X^M and P^M, which has not been previously noticed by physicists, namely that forces can act not just on P^M, but also on X^M. However, X^M and P^M are related by the fourier transform. Therefore a force which acts upon X^M has a fourier transform which acts upon P^M and vice versa.[31] As a result, the fourier transform of the x-strong interaction can act in the momentum sector to change momenta, as if it were an intermediate or long-range form of the strong interaction.

We have now shown that this theory predicts the existence of a second strong interaction which can produce long-range effects (ie outside normal particles and nuclei) and also change momenta. The strength of this new force is the same as that of the unified field ($\alpha_{x\text{-}s} = \alpha_{GUT}$) which has the value $\alpha_{GUT} = 0.04 \pm 0.003$ at $10^{16\pm0.3}$ GeV.[32]

In the previous paper, we have found evidence for a new force of nature which has the strength $\alpha_c = 0.043 \pm .005$. Thus we find:

$$\alpha_c = \alpha_{x\text{-}s} \tag{7}$$

Therefore, these two forces have the same strength and the same properties: they are both strong interactions which are not confined. *Therefore they are the same force.* QED.

We have thus explained the existence of the order force - it is the x-strong interaction. Furthermore, the existence of this new force provides the first experimental confirmation of this string theory of Bars et al with two time dimensions.

Summary

Bars and Kounnas have proposed a string theory with two time dimensions (10,2), in which one time dimension is in the expanding part of the universe, and the other is in the compactified part inside microscopic matter. Bars and his colleagues have shown that gauging the Sp(2) duality symmetry of quantum mechanics is an elegant way to generate a theory with two time dimensions and two physical sectors. This theory creates position, momentum and force out of nothing, which are the basic "ingredients" of physics.

They find that far from being a hindrance, two-time physics is a boon, because it provides the basis for unifying many features of one-time physics in a geometrical manner. Their theory starts to be a master theory which incorporates all single time physics.

This theory predicts the existence of two physical sectors: one for momenta, the other for coordinates. The existence of these two physical sectors enables one to start to understand the counter-intuitive phenomena of quantum mechanics, such as wave-particle duality, tunnelling, and Heisenberg's uncertainty principle. These provide preliminary evidence for the validity of this theory.

Conclusions

We show that this theory predicts two unification hierarchies, the hierarchy known to physics in the momentum sector, and a second hierarchy. The second unification hierarchy is in the coordinate sector, and gives rise to coordinate-space forms of the strong, weak and electromagnetic interactions. *We show that the coordinate-space strong interaction is not confined and has the same strength as the unified field, and hence of the order force.* Therefore, this theory predicts the existence of the order force which we have found in the previous paper.

The existence of the order force provides further confirmation of this theory. Not only is there a new force of nature, but physical reality is at least twice as complex as we have thought.

References

1. February 3, 1998, revised September 16, 1999, December 18, 2000, May 29, December 6, 2001, July 24, 2003.

2. A.M. Hull & P.K. Townsend, Nucl. Phys. **B 438** (1995) 109; P.K. Townsend, Phys. Lett. **B 35** (1995) 184; E. Witten, Nucl. Phys. **B 443** (1995) 85.

3. E. Witten, Nucl. Phys. **B 443** (1995) 85; J.H. Schwarz, Phys. Lett. **B 367** (1996) 97.

4. T. Banks, W. Fischler, S.H. Shenker, L. Susskind, Phys. Rev. **D 55** (1997) 5112.

5. H. Nishino and E. Sezgin, Supersymmetric Yang-Mills equations in 10+2 dimensions, Phys. Lett. **B 388** (1996) 569.

6. C. Vafa, Evidence for F-theory, Nucl. Phys. **B 469** (1996) 403.

7. D. Kutasov & E. Martinec, Nucl. Phys. **B 477** (1996) 652; C.M. Hull & P.K. Townsend, Nucl. Phys. **B 438** (1995) 109; P.K. Townsend, p-brane democracy, in: Particles, Strings and Cosmology, ed. J. Bagger (World Scientific, 1996), hep-th/9507048; I. Bars & S. Yankielowicz, Phys. Rev. **D 53** (1996) 4489; I. Bars, Supersymmetry, p-brane duality and hidden space-time dimensions, hep-th/9604139; I. Bars, Phys. Rev. **D 55** (1997) 2373.

8. I. Bars & C. Kounnas, Phys. Lett. **B 402** (1997) 25; I. Bars, Phys. Lett. **B 403** (1997) 257.

9. E. Sezgin, Phys. Lett. **B 403** (1997) 265.

10. I. Bars, Phys. Rev. **D 55** (1997) 3633.

11. A. Strominger & K. Vafa, Phys. Lett. **B 379** (1996) 99; G. Horowitz, J. Maldacena & A. Strominger, Phys. Lett. **B 383** (1996) 151; M. Cvetic & A.A. Tseytlin, Phys. Lett. **B 366** (1996) 95; R. Djikgraaf, E. Verlinde, hep-th/9603126.

12. I. Bars & C. Kounnas, Phys. Lett. **B 402** (1997) 25.

13. I. Bars, Phys. Rev. **D 55** (1997) 2373.

14. A.A. Tseytlin, Nucl. Phys. **B 350** (1991) 395.

15. They do not suggest an explanation for a third time, but this could possibly be included in theories with sub-quarks or preons.

16. I. Bars, in the Proceedings of the Conference Frontiers in Quantum Field Theory, Toyonaka, Japan, 1995; I. Bars, Phys. Rev. D **54**, 5203 (1996).

17. I. Bars Phys. Lett. **B 403**, (1997) 257.

18. I. Bars and C. Deliduman, Phys. Rev. **D 56**, (1997) 6579.

19. I. Bars & C. Deliduman, Phys. Lett. **B 417**, (1998) 290.

20. I. Rudychev and E. Sezgin, "Superparticles, p-form coordinates and the BPS condition", hep-th/9711128.

21. I. Rudychev and E. Sezgin, "Superparticles in D > 11", hep-th/9704057.

22. I. Bars, Phys. Rev. **D 56**, (1997) 7954.

23. I. Bars and C Kounnas, Phys. Rev. **D 56**, (1997) 3664.

24. I. Bars, C. Deliduman and O. Andreev, Phys. Rev. **D 58**, (1998) 066004/1-10.

25. I. Bars, Phys. Rev. **D 58**, (1998) 066006/1-10.

26. A. Einstein, B. Podolsky, and N. Rosen, Phys. Rev. **47** (1935) 777.

27. A. Aspect et al, Phys. Rev. **49** (1982) 1804; N. Gisin et al, Phys. Rev. Lett. **81**, 3563-3566 (1998); Phys. Rev. **A 59**, 4150-4163 (1999).

28. A more complete theory should provide the formalism of quantum mechanics and the relationship between the matter and vacuum sectors.

29. Note that the implication of this theory is that confinement is a result of the different topological structures of the momentum and coordinate sectors.

30. If there is some slight symmetry breaking in the coordinate sector, there could be some kind of nebulous, almost massless "matter" in that sector. If so, the "x-quarks" would presumably not be bound because the x-strong interaction is so weak. This could explain why fractional charge has apparently occasionally been seen, but the experiments cannot be repeated, because these charges are not attached to normal matter.

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32. U. Amaldi, W. de Boer and H. Fürstenau, *Phys. Lett. B* **260**, 447 (1991).